

LOCALIZATION OF ONE-PHOTON STATE IN SPACE AND EINSTEIN-PODOLSKY-ROSEN PARADOX IN SPONTANEOUS PARAMETRIC DOWN CONVERSION

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An experiment on one-photon state localization in space using a correlation technique in Spontaneous Parametric Down Conversion (SPDC) process is discussed. Results of measurements demonstrate an idea of the Einstein-Podolsky-Rosen (EPR) paradox for coordinate and momentum variables of photon states. Results of the experiment can be explained with the help of the advanced wave technique developed by D.N.Klyshko /1,2/.

The experiment is based on the idea that two-photon states of optical electromagnetic fields arising in the nonlinear process of the spontaneous parametric down conversion (spontaneous parametric light scattering) can be explained by quantum mechanical theory with the help of a single wave function. The interaction of monochromatic laser radiation with a nonlinear crystal without a center of symmetry results in the spontaneous emergence of two-photon states with a broad set of different coordinate-momentum and energy-time pairs of variables. The radiation after the nonlinear crystal has a continuous distribution of wavevectors in space depending on the nonlinear properties of crystal and phase matching conditions $\omega_1 + \omega_2 = \omega_L$, $\mathbf{k}_1 + \mathbf{k}_2 = \mathbf{k}_L$. This forms the main reason why we can easily measure coordinates or wavevectors of photons. The typical experimental setup for the measurement of the distribution of scattered radiation in space as a function frequency that have being used in our earlier works /3-5/ is illustrated in Fig.1. Ultraviolet radiation at $\lambda = 325$ nm from a He-Cd laser interacted with a 2 cm long nonlinear LiIO_3 crystal and created broad band scattered radiation centered at $\lambda = 650$ nm. The radii of rings in the focal plane of the collecting lens are defined by phase matching conditions. The

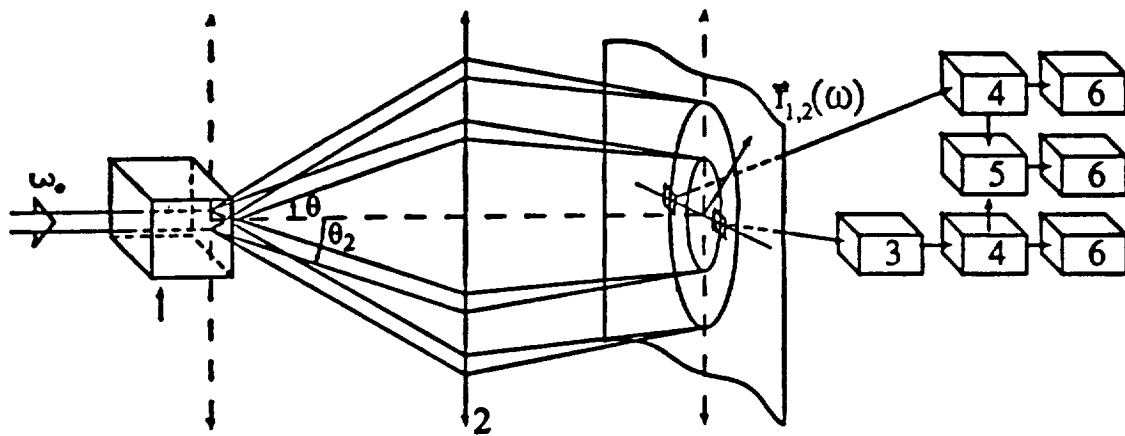


Fig.1. Outline of the experimental setup for the investigation of correlation properties of radiation in the spontaneous parametric down conversion process. 1- nonlinear LiIO_3 crystal, 2- collecting lens, 3-spectral device, 4- photodetectors, 5- coincident circuit, 6- counters.

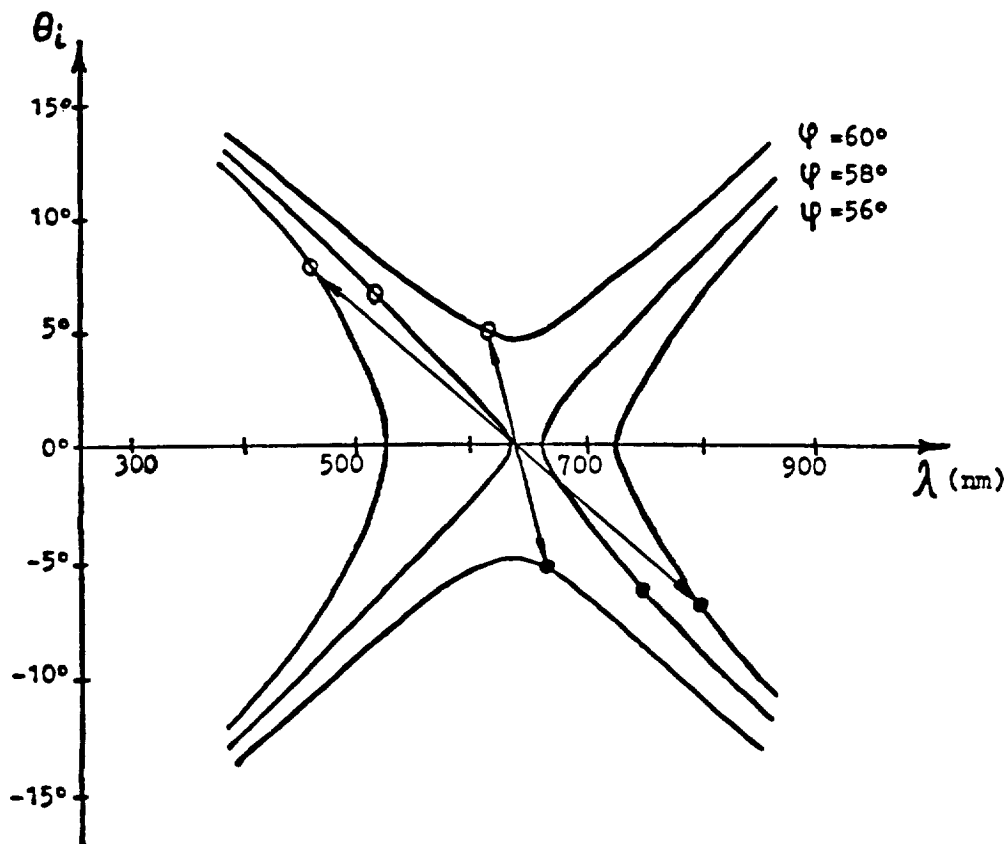


Fig.2. Frequency-angular dependence of scattered radiation. the symbols \bullet and \circ denote the photons conjugated by phase matching conditions.

thickness of rings of different frequency depends on the parameters of spacial coherency and the focal length of collecting lens 2.

The frequency-angular dependence of scattered radiation for the different orientations of the optical axis (z) of the crystal with respect to the laser beam wavevector \mathbf{k}_L is shown in Fig.2. This dependence was measured with the help of a spectral device placed in the focal plane of the collecting lens.

The region of one-photon state localization was determined from measurements of the fourth-order space correlation function $G^{(2)}(E^{(-)}(\mathbf{r}_1)E^{(-)}(\mathbf{r}_2)E^{(+)}(\mathbf{r}_1)E^{(+)}(\mathbf{r}_2))$. The three-dimensional shape of that function was measured by scanning in space using micro holes (see Fig.3). The micro holes had a diameter much smaller than the space coherence area of radiation and were connected with photodetectors by fibers. The point of maximum probability of one-photon state localization along the z -direction was calculated by using a Gaussian approximation to the shape of the space correlation function and projecting the half-width dependence onto the x - z coordinate plane (see Fig.4).

It was found in our first experiment that the location of the point giving the maximum probability of one-photon state localization depended on the location of the reference photodetector in space. This result demonstrates the EPR paradox conditions for coordinate and momentum variables. We note here that the indirect measurement technique used here gave only a qualitative result. The accuracy of the first experiments was about 30-40%. We had to use a method of interpolation of the space correlation function shape because the time resolution of our electronics correlation circuit ($\tau \approx 1\text{ns}$) could not allow us to make a direct measurement of the precise space point of photon localisation.

The result of the experiment could be easily interpreted with the help of the theory of hypothetical advanced Green functions /1,2/ and classical lens equations if the nonlinear crystal is considered as a mirror. However, it does not mean that real advanced electromagnetic waves exist.

We look forward to improvements of time parameters of our experimental apparatus to provide a quantitative result in the measurement of coordinate and momentum variables of optical fields generated in the SPDC process. Such work is in progress.

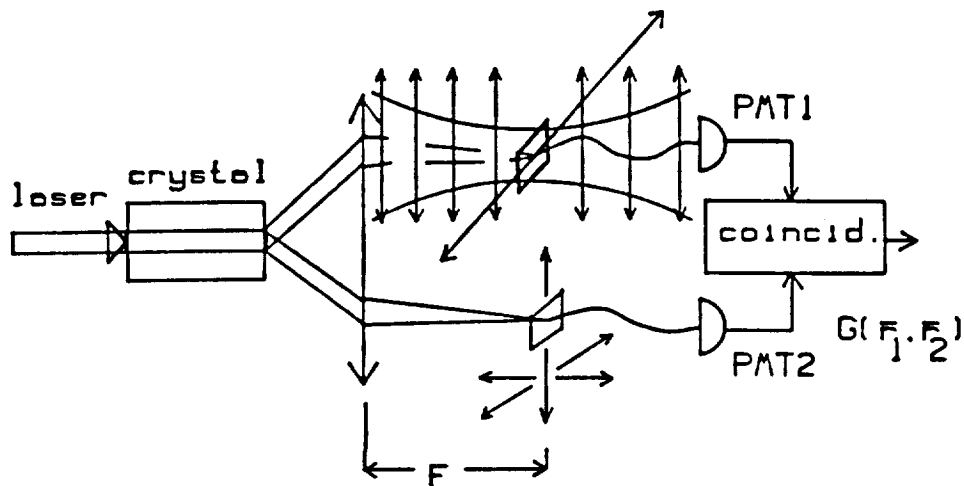


Fig.3. Outline of measurement of fourth-order space correlation function $G^{(2)}(r_1, r_2)$.

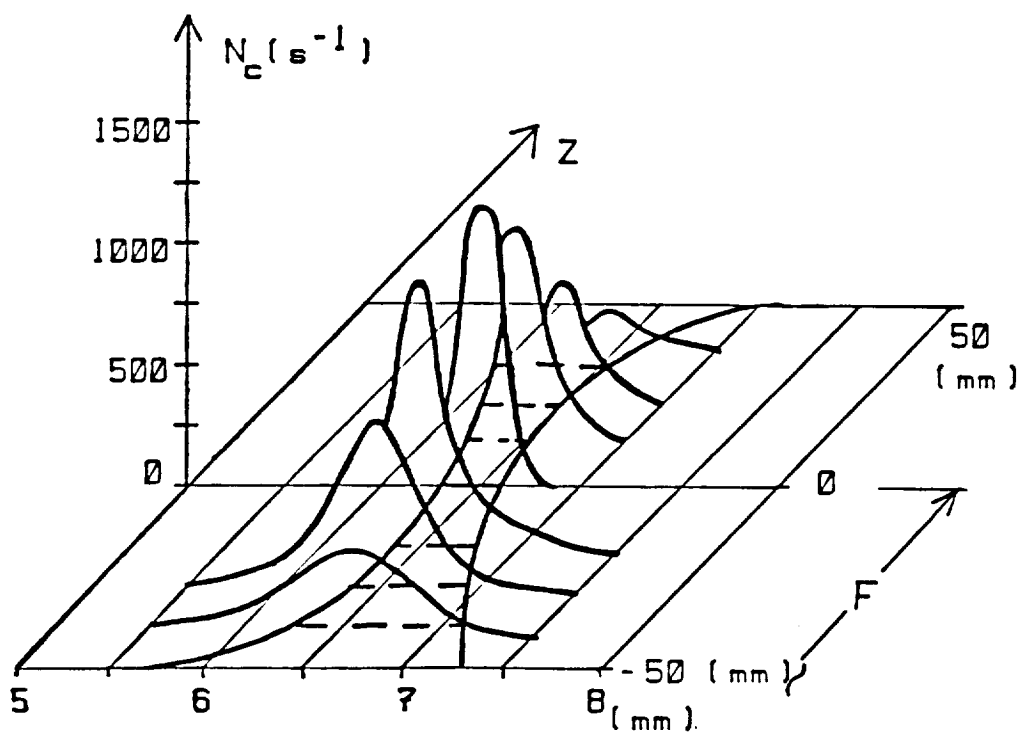


Fig.4. Result of the $G^{(2)}(r_1, r_2)$ space distribution measurement. The point of maximum probability of photon localization was calculated by interpolation of projection of half-width of correlation function value in a Gaussian shape approach on the x - z -plane.

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